Comparative Study of Remote Surgery Techniques

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Abstract-**Remote surgery is the method by which a doctor can perform surgery on a patient from a remote location. The main reason for developing this kind of technique is to treat emergency patients from a long distance. This paper surveys the research work performed regarding the topic. Detailed case studies of work regarding this topic across the world have also been compiled. Apart from this, the various factors of improvements needed to make commercial remote surgery successful have been discussed in detail. This paper focuses first on the various operational concepts behind remote or robotic surgery. In this paper, a detail study of the structure and design of the robotic hand has been provided. However, this technology is still in its nascent stage and needs considerable improvement to be made commercial. Attention has been drawn to research about bio compatible materials which will not react with the body and cause harm. The final aspect of robot surgery that has been discussed in this paper is the wireless communication between the remote stations. Attention has been drawn to the points of improvement in the communications infrastructure. It was concluded in the paper that although the idea of remote surgery has been conceived long ago, not much work has been done on improving the precision of the robotic system, bio compatibility of the robotic arm and the communications infrastructure of the system to make it commercially feasible.**

I. INTRODUCTION

Surgery is a serious field in medical science as it deals with life and death situations. The recent advancements in wireless communication and robotic systems has made researchers experiment with the idea of remote surgery. Remote surgery is the method by which a doctor can perform surgery on a patient from a remote location. The main reason for developing this kind of technique is to treat emergency patients from a long distance. In this technique, the doctor is provided with a computer in another location where he can see the image of the operation theater. The area to be operated on is exposed to the doctor with camera fixed around the patient and the doctor controls the robot to do the surgery with the help of the computer provided [1]. The whole process is supported by a specially designed software. A robotic arm is designed and placed in the operation theater which is regulated by the doctor with his computer. He keeps on doing the surgery by moving that robotic hand from his location.

The architecture of the robotic arm is crucial. It has to be so designed that it becomes easy to put it into delicate and narrow areas in the body with ease. For precision and ease of movement, the arm has to be light, compact and slick. The system usually comprises of a remote control station operated by an electric processor unit and a local station that consists of the robot, surgical equipment, sensors and a monitoring station. However, this technology is still in its nascent stage and needs considerable improvement to be made commercial. The factors which decide the performance of the system is time delay. It is a very important factor as timing is crucial in surgery. A few seconds of time delay can be fatal for the patient. Not much of work has been done in improving precision of time delay and hence, the consequences of inaccuracy of timing during surgery have been highlighted in this paper. Another important factor is the range of movement of the robotic arm. The movement intended by the doctor during surgery should be exactly equal to the movement done by the arm. The arm should be flexible enough and its degree of rotation should be sufficient for operation. Therefore, considerable research needs to be done on the accuracy of distance of rotation of the robot arm compared to the actual hand of the doctor. For robotic surgery, this accuracy is very important otherwise the surgery can never be successful.

Remote surgery needs a lot of precaution to be taken for the construction of the robot as well as the system. In robotics, several types of materials are used to construct the robot but as these kinds of robots are meant for human surgery, the bio compatibility of the arm needs to be considered. During surgery, the arm gets exposed to the open internal section of the body and it also comes in touch with blood and internal body organs. Hence hygiene and operational safety is very essential[2]. At the same time, the robot made up of bio compatible materials should be efficient enough to do precise movements and rotations and light and slim enough for operation on various body parts. Further details about the design aspects and bio compatibility are discussed in the paper. The further away a doctor gets from the operation theater, the weaker becomes the communication. So, it is important to know the maximum distance that can be considered to conduct a remote surgery. With the weakness of communication between the two locations, a lot of error interference pops up, and the accuracy of the technology decreases. A big time lag can occur with the weakness in wireless communication which can be dangerous for the patient.

So, in this paper, we have drawn attention to the points of improvement in the communications infrastructure. Considerable research and development is necessary to develop the network of wireless communication to make

surgery possible from anywhere possible however long distance it is.

II. BACKGROUND

The main reason for developing this kind of technique is to treat emergency patients from a long distance. There arises a considerable amount of cases where the condition of the patient remains so critical that it may be fatal to shift the person from one place to another. In this case, remote surgery can prove to be the difference between life and death. Surgeons do not have to move to remote locations to perform surgeries for critical patients. Remote surgery can prove to be extremely beneficial for treating soldiers in the frontline. During war, the soldiers may need treatment at very short notice. It is risky and even sometimes impossible to take doctors to the war field to treat them. The best way of doing surgery on them is remote surgery. The doctors can operate on them from a safe location any part of the world. Similar logic works for the astronauts who go for a space mission for years. NASA is working on remote surgery technique to develop space robots[6]. After that they are planning to train some of the astronauts to operate these robots for surgery. Table I lists the difference between a conventional and robotic surgery. The first Robotic surgery took place in 2001 between New York and France on a 28 year old lady[3]. This operation was named Lindberg Operation. Till now, two robotic models are available that are used for robotic surgery. The first one is named *da vinci* and it costs $1 million. Another model is ZEUS and it costs $950,000 [4] .

Table I
DIFFERENCES BETWEEN CONVENTIONAL AND ROBOTIC SURGERY

Factors	**Conventional Surgery**	**Robotic Surgery**
Physician	Physically present in front of the patient	Physically present far away from the patient
Power supply	Can still be continued in case a power cut	Is totally electricity dependent
Image	Might not be clearly visible sometimes	Because of camera, perfect image is obtained
Eyes	Can concentrate on one thing at a time	Can view image of two things at the same time.
Hands	Human hand may not reach precisely inside the body	Robotic arm is designed to reach narrow and delicate areas inside the body.
Blood Loss	Huge	Less due minimally invasive technique

III. COMPONENTS

The three main components of Remote Surgery are the operation site, the surgery site and the communications infrastructure.

Operation site-Operation site is the place from where the physician or surgeon controls or operates the surgery. It can be the residence of the physician or might be some hospital. The place should contain complete setup to conduct a surgery. From the same place the surgeon can handle surgeries in different places. The setup comprises of a computer and with the help of joystick, the physician performs all the jobs from there. The operating systems that are used usually are Windows and Vx Works[11]. The total control of the robot is done using this software. Compared to windows, Vx Works functions better as it is a specially designed real time operating system. A software package called Digital Video Transport System (DVTS) has been used to transmit the video from the operation site to surgical site and vice versa.

The physician controls the movement of the robotic arm and eyes from the operation site. The surgical robots are not intelligent robots and hence all the decisions and tasks are actually performed by the doctor from this site [10]. The doctors use a special software to do this tele-surgery. Voice-controlled robotic models are now available, i.e., surgeons can control the movement of the robotic through certain vocal commands.

The operation site should have extremely fast responding instruments as a delay of even a second can be the difference between life and death. A big screen is there to receive both 3D and 2D images. Two monitors are provided to visualize two images at a time. The operation site consists of knobs by which the doctor can adjust the force and degree of rotation of the robot in the surgical site performing the operation. The room is sound-proof so that the doctor can concentrate on the surgery in a noise-free environment. Multiple doctors may be present at the operation site to provide suggestions during the procedure.

Surgery site- Surgery site is the area where the operation actually takes place on the patient. Here, a robot is predesigned to performs the surgery on behalf of the doctor. Although the activities of the robot varies from one surgery to another, the basic structure remains same in case of any surgery. The fundamental structure of the robot includes its arms and eyes. Robots can have one or more arms depending on the requirement in the surgery [7]. The arms play a very important role in the whole process as it is the master control that is operated by the surgeon from a distant place. The arms generally have 7 degrees of freedom- 3 translational,3 rotational and 1 for grasping motion [8]. The arms of the robot are fixed just above the region to be operated on the patient. The equipments required to carry out the surgery (scissors, tweezers) are kept in such a distance around the bed ,so that the robotic arm can reach them. Therefore, the length and rotational capabilities of the robotic arm are pre determined and according to that the position of the patient, equipment positions are all calculated. Apart from the arm, another important feature of the robotic structure is the eyes. Previously, a rotating camera was fixed just above the region of operation to give image of the area and surrounding area to the physician. But recent researchers included two cameras to give even more accurate image. The two cameras functions like two eyes of a human being. Rather, it gives

even perfect view that a normal human eye. The two cameras can focus at two sites at the same time and it helps the physician to move faster while taking care of everything safely. 2D and 3D images have really in providing a better view of the internal structure of the patient to be operated [9].Apart from the robot in the surgical room other doctors can also stay for communicating the real time problems or situations to the doctor in the operation site. These doctors do not participate in the surgery directly but they can alert the doctor conducting the operation , if some problem is noticed. They make sure that the robot is well controlled from the operation site and no connection problem or delay is affecting the surgery.

Communications Infrastructure- This is the most important component of robotic surgery. The whole process of robotic surgery is usually done through Internet. But the internet needs to be really fast to conduct a surgery. Surgery is a real time process and hence no delay can be tolerated. Asynchronous Transfer Mode (ATM) is a very high speed network and can transmit 10GB of data in one second [12]. But, this network is also very expensive and hence many cases have used ADSL (Asymmetric digital subscriber Line) and modem as this is cheaper and widespread through the internet. The video is transmitted through ADSL while the voice is transmitted through the modem. Hence, the network needs to be very strong as if it is faces any disturbance the whole system is going to be disturbed and it can take life of a patient.

The overall system of remote surgery is possible due to the recent advancements in wireless communication. The surgery site and the operating site are connected to each other with the help of Internet which is a wireless mean. So, the two sites and the wireless communication network together forms the complete remote surgery architecture. The three components are inter-connected to each other and disturbance in any one of them will cause a big problem. The steps of a remote surgery is explained in Fig. 1, with the help of a flow diagram.

The Doctor need to perform some scans and tests of the patient before operation to understand the pre operative stage of the patient. If some treatment is required before surgery, it is also provided to the patient. The doctor after going through all these results from the operation site , then starts preparation for the surgery. Preparation includes arrangement in both surgery and operative site. The image of the surgery site and all the reports are then sent to the doctor so that he can take some time to plan for the surgery. This also helps in testing the image transmission between the two sites. After the planning is complete ,real time vide is started to get ready for the final task. The doctor then starts controlling the robot from the operative site to do the surgery. After each step, error adjustment is done in order to minimize the error at the operation table .The errors may include the distance between the robotic arm and the target organ or a time delay. When all these positions are fixed, the doctor finally applies pressure to puncture and do the operation.

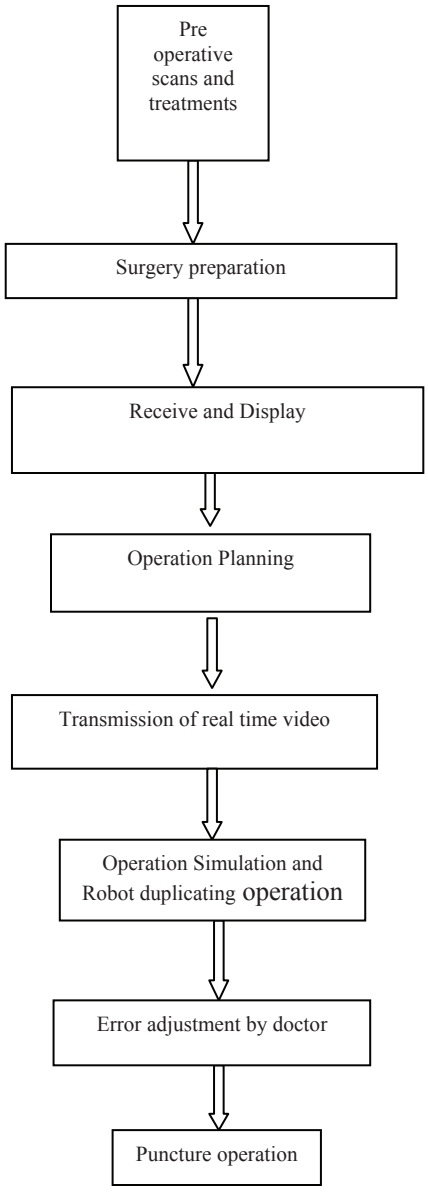

Fig. 1 Flow diagram of all the steps involved in remote surgery

IV.FIRST ROBOTIC MODEL

The first commercialized robotic model which is used everywhere till today is called *da vinci*. It has some specific features which are described below. It gives an overview of the whole wireless remote surgery technique. This model was launched in April 2009. Presently this is the only system available in the market commercially for the doctors to do remote surgery instead of conventional surgery. This system comprises of da vinci robot which has four arms and 3D camera for image capturing[13]. The surgeon receives real time image and it is advised for another surgeon or assistant to stay near the patient. This system cannot be programmed and the robot has no intelligence hence like traditional surgery, the whole system of surgery is controlled by the doctor. Some of the major benefits experienced by the doctors with this set up over traditional surgery is precision, increased range of motion, improved dexterity, enhanced

visualization and good access. It has a lot of safety protocols but as there is always risk in surgery, there is also risk in da Vinci system[14]. It can cause bleeding, infection, internal scarring. This set up got The US Food and Drug Administration(FDA) clearance. da vinci is now used in a hundreds of country to carry out remote surgery research and real surgeries. But, this system is not used to operate from a long distance yet but it can be designed to make it work from remote distances. The main features of da vinci system which are really advantageous are as follows:

- A surgeon touchpad that facilitates video, audio and system settings.
- Surgeons can see four different parameters at the same time.
- There is feature called Endowrist which can select any tool within 5mm and 8mm diameter of the surgical table[15].
- Fingertip control through Endowrist allows precise movements.
- There is a footswitch which allows the surgeon to do multiple works like swapping between different energy equipments .
- There is provision of one step cable connection which saves time.
- There is a motorized patient cart.
- Bright ,High Resolution Image ,3D with 10X magnification which allows surgeons to see the anatomical structures in their natural color[16].
- It allows two surgeons to collaborate during surgery
- The system uses Title Pro multi display system which allows the surgeon to get 3D image and two other sources for Ultrasound and EKG.
- There is an extensibility for digital or integration in this model.
- There is a dual console capability which trains and collaborates during minimal invasive surgery.
- It has intuitive technology which replicates an open surgery by controlling eye hand instrument alignment.

But many features are still to be installed in the system and some features still needs to be improved to make t more efficient a system. The features to be taken note of to be improved are explained with a case study and the reasons why many robotic surgeries even failed and killed innumerable lives.

V. CASE STUDY

A remote surgery was conducted between Japan and Korea by using minimally invasive surgical system. Laparoscopy is a popular Minimally Invasive Surgery to reduce patients burden, hospital stay duration and medical cost. This surgery was successfully carried out on pigs within 50m sec of control signal delay and with an image time delay of 400msec[17].Korea Japan cable network was used to conduct the surgery. The operation site was located in Hanyang University in Korea and the surgery site was located in Kyushu University in Japan which was a distance of about 540 km[18]. A master manipulator was developed at this site and a screen was placed close to it. The master manipulator consisted of foot switches and left and right arm. Each arm had 7 DOF[19]. The operator could send orientation information to the surgical site by operating the master manipulator. The screen displayed the abdominal region of the patient to be operated ,aspect the surgery room and all vital signals of the patient like EEG, Blood pressure.

Another slave monitor has been designed in the surgery room to receive the control signal from the operator and perform the duplicate task. The slave manipulator consisted of three arms among which the middle one cold hold the laparoscope and the side arms could hold forceps. The ISDN and R & d internet were chosen to conduct this over sea surgery. Vx works was chosen as the real time operating system and DVTS was used to transmit visual and auditory signals.

It took 90 min to complete the whole surgery which is equal to the time required in conventional surgery[20]. It took 6msec to transmit the control signal from the master control to the slave control. The image time delay was 800msec.The network connectivity was overall satisfactory but a delay of transmission of data packet was observed every 30 sec. It was an overall successful surgery but all the delays and connectivity errors should be improved to make it more perfect.

SOME OBSERVED FAILURES IN ROBOTIC SURGERY:

1. In 2012 ,a woman died in hysterectomy when the surgeon-controlled robot accidentally nicked a blood vessel[16].
2. In 2007, a man in Chicago died in Spleen Surgery [21].
3. A New York man whose colon was allegedly perforated during prostate surgery[7].
4. A robotic arm hit a patient in the face during a hysterectomy[21].
5.In 2009,a lady underwent robotically assisted surgery to treat endometriosis and after ten days she was run into emergency when the doctors found that her colon and rectum had been torn during the surgery[7].

After long research on the failures of robotic surgery, it was observed that women were more likely to be injured by the robotic surgery technique because about one third of the robotic surgery failure reported to the FDA was during a gynecologic procedure and 43 percent of the injuries were associated with hysterectomies[7].

This report leads to a new path to research the reason of more injury to women than men during the remote surgery technique.

OBSERVED DRAWBACKS OF THE TECHNOLOGY:

The main drawback in the present technology that we should take note of are discussed below. Improving each of these points will make the system more successful and make it commercial. The main aim of a human beneficial technology is to make it commercial so it is really useful for everyone. Otherwise the discovery is not really fruitful.

a) *Time delay*-The first factor is the time delay. It is a very important factor as timing is crucial in surgery. A few seconds of time delay can be fatal for the patient. Not much of work has been done in improving precision of time delay and hence, the consequences of inaccuracy of timing during surgery have been highlighted in this paper. The researches that took place under this topic indicates that around 400msec of time delay is observed and hence this can even be dangerous in case of a surgery[22]. So, it's very important to reduce the time delay to very negligible.

b) *Range Of Movement* -In remote surgery, doctors control the movement of robots from another location. Usually the models available have 7DOF[23].But, even more flexible movement is sometimes required suddenly during the surgery. And, then if the robot cannot move that flexibly then the doctor cannot efficiently handle the operation. Moreover, as this technology gets more and more popular and commercialized, gradually doctors will start robotic surgery in all kinds of surgeries. And, flexibility requirement varies from one type of surgery to another. Presently, all type of surgeries are even tried with this technique but later on as the system improves new surgeries will require more flexible robots. Hence, more work should be done in designing the movement of the robotic arms.

c) *Network Connectivity*-Network Connectivity is the only way to join the two sites- Surgical and Operation. A little disturbance in connectivity mess up the whole procedure. And as the technique deals with human life, network hamper cannot be encouraged. The connectivity is conducted through internet but using normal internet connection makes the files big and it takes more time to get transmitted and it delays the whole process. A very fast network is required to control a live surgery.ATM is a really fast one but from the survey reports, it is seen that it is not sufficient enough[30]. A lot of adverse effects lines up with poor connectivity. Image quality degrades, time delay and image delay enhances with poor network connectivity[24]. This single component affects the whole system and makes it slow. So, special attention is required to be given to this factor.

d) *Biocompatibility*-The robotic arm does the surgery in a remote surgery and hence the robotic hand gets inside the body of the patient and comes in contact with the blood vessels and interior organs[28]. As in conventional surgery doctor required to make sure that his hand is antiseptic, in case of remote surgery we should make sure that the material by which the robotic arm is made is biocompatible. It should not cause any harmful effects on the human body due to its contact. Sometimes the patient faces post operative problems like internal bleeding, organ rupture due to lack of attention in all such issues. Robotic is a part of many researches now a days. But, there the material with which the robots are made are much more flexible but remote surgery robots has to be made from biomaterials[29]. But not much research is yet done on it to improve it and many patients faced post operative problems in remote surgery due to this. So we should take this into serious note.

e) Force-As the robotic arm is controlled by a doctor from remote area, it is very important to estimate how much force is required to be incorporated to do a particular task. Every organ has different properties. Some are rigid enough while others are soft and hence they should be handled very safely. The organs are so delicate that little more force can cause a lot of side effects, post operative emergencies and can even take life of a patient. From the case studies , we have see a lot of reports where the patient faces post operative emergencies and doctors then found their organs ruptured during the operation. Hence, a lot of precaution is required to be taken to do a robotic surgery on a major organ.

f) Security-As the total process of Remote Surgery goes through internet, security is a very big issue. A neuro surgery was conducted in China where a lot of virus attacks are observed during the surgery period[25]. Though not a lot of harmful effect was observed in that surgery due to the virus but this kind of virus attacks can be severe. In any internet connection, security is very essential. Virus attack can block the system and stop the connectivity between the surgical and operation site. In fact Virus can block the images and prevent the doctor from getting the actual accurate image of the operation theatre[26]. It can even degrade the quality of the image and hamper the whole process. Not only virus attack but also the access of the system should be prohibited to public. Except the doctor ,no one should be able to access it during the surgery as modification of any data can result in a wrong step in surgery killing the patient[27]. Many surgeries that has been conducted have faced security problem and hence this is a serious topic to be noted in this field. A list of Pros and Cons of Remote Surgery is stated below in Table 2.

Table 2 : PROS AND CONS OF REMOTE SURGERY

PROS	**CONS**
Accurate	Time Delay
Detail Image Capture(2D, 3D image)	Movement
Applications(soldiers, Astronauts)	Security(Virus Attacks and public access)
	Biocompatibility
	Network Connectivity
	Force(Estimation of force exerted by master controller and actual force exerted on patient by Slave controller)
	Serious Training required to operate the system

SOME IMMEDIATE REQUIRED STEPS:

a) Doctor's Training-Surgery is a very delicate task and a surgeon can perform a surgery only after a prolong experience. Even junior surgeons are not allowed to operate on a patient alone and are always accompanied by an experienced doctor to do the surgery. Robotic Surgery is a very new field and a robot performing surgery in this case does not really mean that the doctor's responsibility is reduced. It is a process where the doctor completely needs to take part and apply all his knowledge to make the surgery

successful. the robots are not intelligent robots and hence are completely controlled by the doctors. The robots are only used to give precision to the process and overcome the problem of distance and place in many cases as discussed in this paper. Hence , a doctor must get trained very well before doing a robotic surgery. Even experienced doctors need to take special trainings as this is much different from a real hand to hand surgery. This type of surgery is more technical and hence a doctor should gain the technical knowledge s how much force, rotations to be done along with medical knowledge.

da Vinci system provides audio video training system which the doctors should follow very well. It is said that at least a doctor should do sixteen to eighteen robotic surgeries in order to get expertise in the field. The main reason of the failures of robotic surgery is lack of practice by the physicians and hence they could not estimate properly during the surgery. But, surgery is not a field to experiment. Hence, instead of doing directly on human body, doctors should practice surgery on artificial organs to get grip on the subject. Moreover, hospitals conducting Remote surgeries should conduct special training sessions for their doctors to get trained in this technology.

b) Cost Reduction-Presently the two popular robotic surgery models costs around 1 million dollar. The whole setup of the remote surgery is highly technical and made of good material quality as it is used on human body. In fact, the present set up is not sufficient enough to carry on and need to be even more developed. More expense is going to add up to the present model to eliminate all the disadvantages. So, as a result the set up would cost more in near future. As a result ,it will not be possible for all the hospitals to afford such a set up. Even the developing countries needs to be well connected to the technology as more and more patients take expert suggestions of physicians in developed countries. Hence remote surgery is very much essential to be conducted between these two types of countries. But, due to so high cost the hospitals in poor areas cannot afford such a system and that would really make the discovery unsuccessful as such treatments were one of the prime reasons which ushered the development of remote surgery technique. Hence, along with development of the set up, the budget should be kept in mind. Products which are cheap as well as safe should be selected to reduce the cost t make the product commercialize.

VI. FUTURE GOAL

Our future goal is to make this Remote surgery technique more successful. It will then be more commercialized. To make this happen ,we should seriously take note all the drawbacks and work on them to improve. A single drawback will make the whole technology fail. And ,as surgery is a very serious issue and as it risks a patients life, we cannot take any risk by experimenting. Rather, we should minutely try to develop each and every drawback of the current model and make it successful. At the same time, we should again take note of the cost of the system. the current robotic model is very expensive and hence our future goal would be to design a model that is perfect and improved and cheaper at the same time. Until and unless a technology gets commercialized and helps everyone ,it is not fruitful So, our goal should be to make each and every hospital and doctor to use a perfect cheap remote surgery set up to give the patients more accurate surgery than conventional on hand technique. We have to utilize the advantages of this technology to make it more popular and successful.

VII. CONCLUSION

Remote surgery or Robotic surgery is undoubtedly a very good technology. But , as it deals with human life, it is very a very serious technology and hence a lot precaution and testing and improvements are required. Remote surgery has already achieved 60% success but now it needs to be more precisely developed to overcome all of its disadvantages. Though the technology started in 2001 but not much development is made to make it cheap. It is so highly expensive that it is still not used that commonly.This technique will be remarkably useful but before that we have to make sure all the drawbacks have been improved. Otherwise the failures in the technology are going to scare the common people and then it will not be acceptable anymore by the patients. Hence, the advantages of the technique should be strengthening and the drawbacks should be eliminated carefully. And before applying on human body, it should be tested well on artificial organs and sufficient training should be provided to the surgeons.Future researchers should focus on the small drawbacks of the technology to make it stronger. With these developments, this technology is going to be a remarkable discovery in medical science. And gradually it will get more commercialized and will make critical surgeries possible with ease.

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